

REPORT DOCUMENTATION PAGE

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14. ABSTRACT

Two high-speed imaging systems were acquired for ongoing combustion research supported by AFOSR and ARO. All research programs involve extensive experimentation of unsteady flows, such as the bouncing/merging events for colliding droplets, the propagation of high-speed premixed flames, and the complex ignition kinetics in turbulent flows. Superior spatially and temporally resolved images have since been obtained with these systems.

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15. SUBJECT TERMS

Droplet collision; droplet-film collision; droplet bouncing; droplet coalescence; flame propagation; cellular flames; flame-front instabilities.

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Final Technical Report
(June 1, 2001 to December 31, 2003)

**HIGH-SPEED IMAGING SYSTEM FOR DROPLET COLLISION
AND
UNSTEADY COMBUSTION STUDIES**

(F49620-01-1-0233 - DURIP)

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Need for Equipment

The funding was used to acquire a high-speed camera system for use in ongoing research supported by AFOSR (*Dynamics of Droplet Collision and Flamefront Motion*, Contract No. F49620-00-1-0092, and *Physical and Chemical Processes in Flames*, Contract No. F49620-98-1-0075), and ARO (*Chemical Kinetics and Aerodynamics of Ignition*, Contract No. DAAG19-01-0004). All research programs involve extensive experimentation of unsteady flows, with the first investigating bouncing/merging criteria for colliding droplets, the second dealing with the response of rapidly propagating unsteady flames exhibiting intrinsic cellular and pulsating instabilities, and the third investigating the inherently complex nature of ignition kinetics in turbulent flows.

For droplet collision studies, the major thrusts involve the determination of the bouncing/merging criteria and the evolution of the collision topology. During such processes, experimental observations of the deformation of the liquid phase prior and subsequent to impact are essential in characterizing the phenomena. With the characteristic time scale for such interaction on the order of tens to hundreds of μ s, a high-speed imaging system of sufficient spatial and temporal resolution is requisite.

For the unsteady flames, the propagation velocity of the flame front can be extremely fast, of the order of hundreds of cm/s. During this period the flame surface could also develop cells as well as pulsate. In order to properly resolve the flame surface during the transient, a high-speed imaging system is again required.

Finally, ignition in systems with turbulent flows and inhomogeneities in both temperature and species concentrations play an important role in many combustion processes. Experimentally, it is of fundamental importance to study the development of the ignition kernel (on the order of 1 ms), which can be investigated with a suitable optical system with high-speed imaging capability.

Acquired High-Speed Imaging Systems

Since the award of the grant, fierce market pressure and rapid technological development had enabled us to acquire two high-speed imaging systems capable of recording rates

from 30 to 40,000 pictures per second, with sufficient spatial resolution. Specifics of the system components are listed in the following:

1. Phantom V5.0 camera upgraded to Phantom V7.0 monochrome camera.
2. Phantom V7 color camera
3. Two computer systems for the two cameras.
4. Optical accessories

Results

Perhaps the best means of presenting the results of the funded program is to show the superior images obtained with the camera systems acquired. Thus Figure 1 shows typical collision images of a $\sim 200 \mu\text{m}$ droplet with a thin film of the same liquid. The total duration of the images shown is 0.25 ms. Figure 2 shows exploding stoichiometric propane/air flames at different pressures. The total durations are of the order of 15 to 20 ms. Images at much finer temporal resolutions have also been obtained.

Publications

1. "Cellular Instabilities and Self-Acceleration of Outwardly Propagating Spherical Flames," by O.C. Kwon, G. Rozenchan and C.K. Law, *Proceedings of the Combustion Institute*, Vol. 29, pp. 1775-1784 (2002).
2. "Outward Propagation, Burning Velocities, and Chemical Effects of Methane Flames up to 60 Atmospheres," by G. Rozenchan, D.L. Zhu and C.K. Law, *Proceedings of the Combustion Institute*, Vol. 29, pp. 1461-1470 (2002).
3. "An Optically Accessible High-Pressure Combustion Apparatus," by S.D. Tse, D.L. Zhu, and C.K. Law, *Review of Scientific Instruments*, Vol. 75, No. 1, pp. 233-239 (2004).
4. "On the dynamics of Head-On Droplet Collision: Experiment and Simulation," by K.L. Pan and C.K. Law, Paper No. AIAA 2004-1159, 42nd Aerospace sciences Meeting, Reno, NV, Jan. 5-8, 2004.

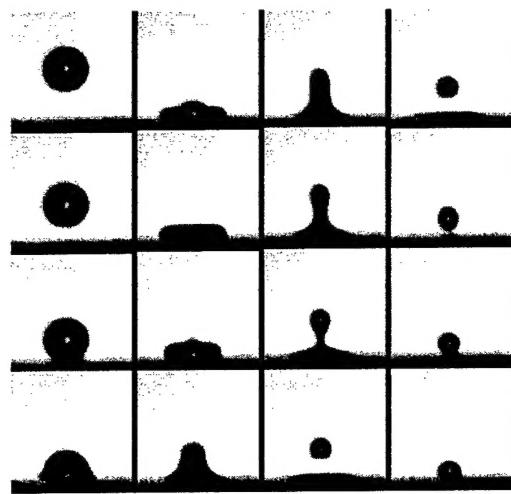


Figure 1

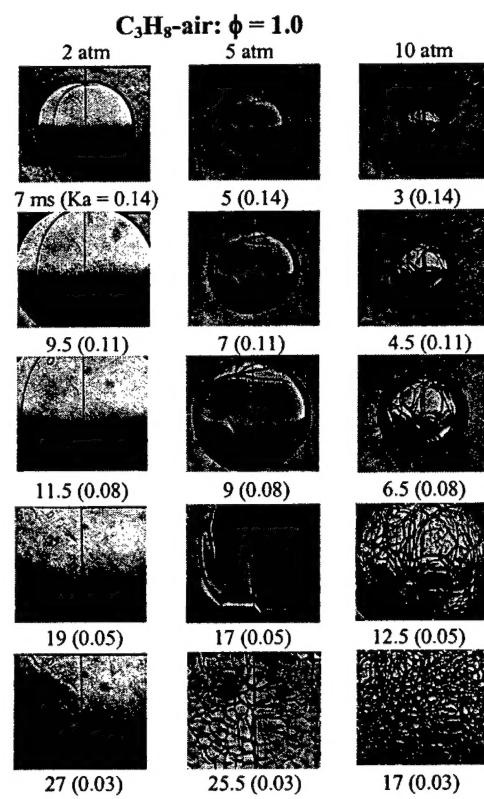


Figure 2